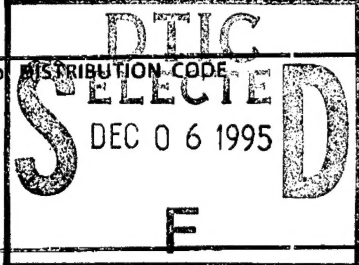


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Final
~~Annual~~ Technical Report

July 1, 1994 to June 30, 1995

The work on the last year of this ASERP grant focused on three topics:

- Passive alignment of a semiconductor laser array to single mode optical fibers
- Etched v-grooves in GaAs wafers
- Alignment tolerant structures.

These three topics will now be described.

Passive Alignment of a semiconductor laser array to single mode optical fibers

The development of a simple and reliable passive alignment scheme for coupling single-mode fibers to single transverse and lateral mode semiconductor lasers is highly desirable since such an approach would considerably reduce the packaging cost of these lasers, which is the dominant cost of the final product. In contrast to passive alignment techniques, active alignment techniques are very much time consuming and require turning on the laser during alignment.

Passive alignment can be performed through structural, solder bumps, or using a visual technique. These techniques can then be characterized as hybrid or monolithic. In the hybrid approach, a different material is used to support the fiber from the one used for the lasers. The alignment is then typically done by either butting the side facets or the notched edges of a semiconductor laser chip against pedestals on the substrate surface, maybe utilizing the surface tension of a solder bump, or by visually mating the fiducial marks on the laser array bottom face with some marks on the substrate. In the monolithic approach, both the optoelectronic device and the alignment marks are on the same substrate. This is the technique that we have elected to choose for doing passive alignment. The use of a monolithic alignment scheme has the following advantages:

- the alignment process is greatly simplified
- the number of degrees of freedom is reduced
- the number of possible mis-alignments steps is reduced

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- the alignment tolerance is only limited by the lithographic process
- the alignment is less temperature sensitive.

One drawback of the monolithic alignment scheme is the need for dry-etched laser facets.

The fabrication process for the monolithic passive alignment scheme involves the optimization of the following steps:

- Epi-layer removal
- Laser/v-window definition
- Ridge etch
- Laser protection
- v-groove etch
- Negative photoresist and SiO₂ removal
- PECVD SiO₂ deposition
- N-metallization
- P-contact and laser facet exposure
- P-metallization and lift-off
- Laser facet etch.

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All these steps were described in Mr. Stewart Wilson's Masters Thesis and will not be described here.

Optical coupling of a single-mode laser to an optical fiber was shown to give efficiencies of 20 % for a multimode fiber and 7 % for a single mode fiber, limited by an offset distance of 50 μ m due to a non-optimized mask layout. Higher efficiencies can be obtained by reducing the distance between the laser facet and the optical fiber. A typical device was shown to have an average threshold current and slope efficiency of 60 mA and .49 mW/mA, respectively. A threshold current as low as 12 mA and a slope efficiency as high as .76 mW/mA were also measured. The typical device also displayed an average turn-on voltage and differential resistance of 2.3 Volts and 12.3 Ohms, respectively.

This work clearly demonstrated the power of a passive alignment technique for aligning single mode fibers to an array of single-mode semiconductor lasers. By optimization of the

mask, it should be possible to get reasonably large butt-coupling efficiencies to single-mode fibers using this technique.

2. Etched v-grooves in GaAs

Preferred etching habit planes are known to be formed as a result of the anisotropy of the crystal structure properties of GaAs semiconductor crystals. In particular, the anisotropic nature of the etching behavior follows from the dependence of the etch rate on crystal orientation. This behavior is especially true for compound zinc-blende-type semiconductor crystals, in particular, III-V semiconductors. Large surface orientation effects can be obtained with such compound semiconductors essentially because more variation in the etch rate occurs for different surfaces. The $\{111\}$ Ga habit plane was reported to be the preferred surface for $[0\ 1\ \bar{1}]$ oriented V-grooves when chemically etching a (100) GaAs crystal surface using a bromine concentration of less than 1.3 % by volume in methanol. $\{332\}$ Ga habit planes have also been reported for V-grooves aligned 11 degrees off $[01\bar{1}]$ in (100) GaAs crystal surfaces using bromine concentration in excess of 5 % in methanol. In the present study, deep V-grooves aligned along the specific $[01\bar{1}]$ direction etched into a (100) wafer surface were found to give (766) and $(\bar{7}66)$ habit planes after etching with bromine concentration of less than 1 % in methanol. These conclusions were reached from using optical microscopy, scanning electron microscopy and analysis of channeling patterns, and transmission electron microscopy of the angular relationships between reference planes. These measurements are tentatively explained by a rotational surface reconstruction of Ga deficient, rehybridized $\{111\}$ planes. These results were written as a paper which was submitted to the Journal of Materials Science: Materials in Electronics for publication.

3. Alignment tolerant structures

Low-loss coupling of semiconductor lasers with single mode fibers, with large misalignment tolerances, is a key technology to effect simple and low cost optoelectronic packaging. To achieve this, the usually elliptic beam from a semiconductor laser has to be mode matched to the circular beam in the fiber.

In our work, we have demonstrated a simple, and potentially low cost, technique using

conventional growth and processing techniques. In our work, the transverse spot size is increased by the use of a diluted waveguide (Al mole fractions are graded from 30 % in the core to 31 % in the cladding). This laser butt-couples into a cleaved single mode fiber with only -1.6 dB loss, and has a -3 dB excess loss misalignment tolerance of ± 3.4 μm in the lateral and ± 1.6 μm in the transverse directions. The laser was found to have a T_0 of 112 K, indicating that the leakage of carriers is not very significant. By providing weak index guiding in the transverse direction, the transverse spot size is expanded from the usual 0.8 μm to 2.6 μm . The transverse mode overlap with the active region is evaluated to be 1.25 %. The lateral mode was controlled by varying the etch depth and width of the ridge.

A 1000 μm long 100 μm wide broad area laser was shown to have a threshold current density of 800 A/cm², which reduced to 350 A/cm² after a 90 % high reflectivity coating was applied on the rear facet. The farfield divergence angles were measured to be 15 deg (transverse) and 4.5 deg (lateral). The near field spot sizes were 2.6 μm in the transverse and 7.0 μm in the lateral directions.

These results were recently presented at the LEOS Annual Meeting in a special symposium dedicated to alignment tolerant structures. Our paper was very well received. Our approach has clearly a lot of appeal in terms of manufacturability and low cost, as compared to techniques that use beam transformers. The latter approaches, based on beam transformers, usually require regrowth and are usually quite complex.

Such a technique, based on alignment tolerant structures and expended beams, can in turn be used in passive components, such as arrayed waveguide gratings for spectrally filtering an input composed of many frequencies. This was recently demonstrated in a closely related program at the University of Maryland with arrayed waveguide gratings and single mode fibers.